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Multiplicity dependence of identified particle production in proton-proton collisions with ALICE

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Abstract

The study of identified particle production as a function of transverse momentum (p_{T}) and event multiplicity in proton-proton (pp) collisions at different center-of-mass energies ($\sqrt{s}$) is a key tool for understanding similarities and differences between small and large collisions systems. We report on the production of $\pi^{\pm}$, $K^{\pm}$, K^0_S, $p(\bar{p})$, $\Lambda(\overline{\Lambda})$, $\Xi^{\pm}$ and $\Omega^{\pm}$ measured in pp collisions in a wide range of center-of-mass energies with ALICE [1]. The multiplicity dependence of identified particle yields is presented for $\sqrt{s}$ = 7 and 13 TeV and discussed in the context of the results obtained in proton-lead (p-Pb) and lead-lead (Pb-Pb) collisions, unveiling remarkable and intriguing similarities. The production rates of strange hadrons are observed to increase more than those of non-strange particles, showing an enhancement pattern with multiplicity which does not depend on the collision energy. Even if the multiplicity dependence of spectral shapes can be qualitatively described by commonly-used Monte Carlo (MC) event generators, the evolution of integrated yield ratios is poorly described by these models.

Keywords: Multiplicity dependence, collectivity, small systems

1. Introduction

Measurements of hadron yields as a function of multiplicity in p-Pb collisions at $\sqrt{s}$ = 5.02 TeV revealed trends reminiscent to those observed in Pb-Pb collisions [2] and usually associated with the creation of a strongly interacting medium, the Quark-Gluon Plasma (QGP). Even more remarkably, a similar behavior was observed for particle production in high multiplicity pp collisions [3]. Features like baryon-to-meson ratio enhancement at intermediate transverse momentum (p_{T}) in Pb-Pb collisions are understood as a consequence of quark coalescence [4] or radial flow [5]. The latter is characteristic to hydrodynamical expansion of the system and its presence might require a fireball in local thermodynamical (kinetic) equilibrium. Similar dynamics observed in smaller systems such as pp or p-Pb, where hydrodynamics was assumed to be not applicable due to the absence of a QGP phase, can be explained by certain QCD effects like color reconnection [6, 7].

On the other hand, increased abundances of strange hadrons in heavy-ion collisions relative to that in pp was originally proposed in 1982 as a signature of QGP [8] and was first observed in Pb-Pb collisions at SPS [9]. Alternatively, in statistical hadronization models [10] the observed strange particle abundances across collision systems can be explained as a canonical suppression of strange quark production in pp collisions, which then gradually subsides for larger system sizes [11].

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To understand how important the initial system configuration are for the final state observables, one would study pp, p-Pb and Pb-Pb collisions. So far, changing the colliding system does not seem to modify relative particle abundances provided that event activities are similar. Now, by comparing the most recent data from pp collisions at $\sqrt{s} = 13$ TeV to that at lower energies, we can isolate the center-of-mass energy dependence of hadrochemistry and kinematics.

2. Analysis and results

The analysis of a 50M minimum bias (MB) triggered event sample of pp collisions at $\sqrt{s} = 13$ TeV, recorded by ALICE [1] in 2015, has lead to the measurements of the production of π, K, p, strange and multi-strange particles. A hit in either V0 scintillators or in the SPD in coincidence with signals from beam pick-up counters was used for MB triggering and events containing more than one primary vertex within $|z| < 10$ cm were discarded as pileup. Acceptance and efficiency corrections were calculated from simulations, using PYTHIA8 (Monash-2013 tune) [6] as particle generator and GEANT3 for describing particle transport in the ALICE detector. In addition, the production of strange hadrons has been studied as a function of the event activity, characterized by the average charged particle multiplicity $\langle dN_{ch}/d\eta \rangle$ measured at mid-rapidity ($|\eta| < 0.5$). To avoid auto-correlations, event activity classes were selected using signals in the V0 detector – two scintillator arrays covering $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$ [1].

Charged pions, kaons and protons were identified in the ALICE central barrel following the approach used in pp collisions at $\sqrt{s} = 7$ TeV [12]. The (multi-)strange baryons and K^0_S were reconstructed using daughter tracks from the weak decays in the rapidity window $|y| < 0.5$.

The p_T-differential p/π and K/π ratios measured in a rapidity window $|y| < 0.5$ in MB pp collisions at $\sqrt{s} = 13$ TeV are shown in Fig. 1, along with similar measurements at $\sqrt{s}$ 2.76 and 7 TeV. While there is no significant evolution of K/π ratios with $\sqrt{s}$, the peak of p/π ratio shifts to slightly higher values of p_T with the increase of $\sqrt{s}$. Note that a minor modification of baryon-to-meson ratio is expected considering a small increase in $\langle dN_{ch}/d\eta \rangle$ with $\sqrt{s}$ [13]. A comparison to PYTHIA8 predictions reveals that not only K/π and p/π ratios are not described, but also the evolution of p/π ratio with $\sqrt{s}$ is not captured within the generator framework.

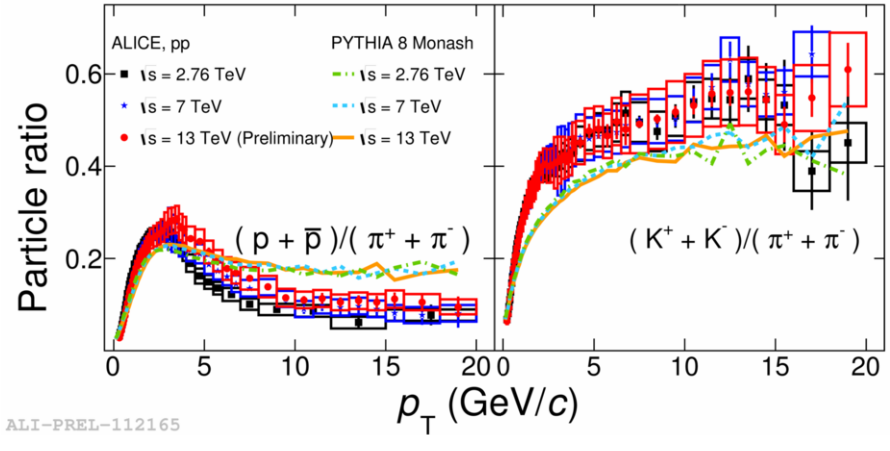

Fig. 1. p_T-differential p/π (left) and K/π (right) ratios measured at different $\sqrt{s}$ with comparison to PYTHIA8 predictions.

The p_T-integrated proton- and hyperon-to-pion ratios as a function of center-of-mass energy have previously been shown in [7]. While p/π ratios saturate at LHC energies, Ξ/π and Ω/π ratios exhibit hints of an increase between MB pp collisions at $\sqrt{s} = 7$ and 13 TeV. To further investigate this enhancement, a

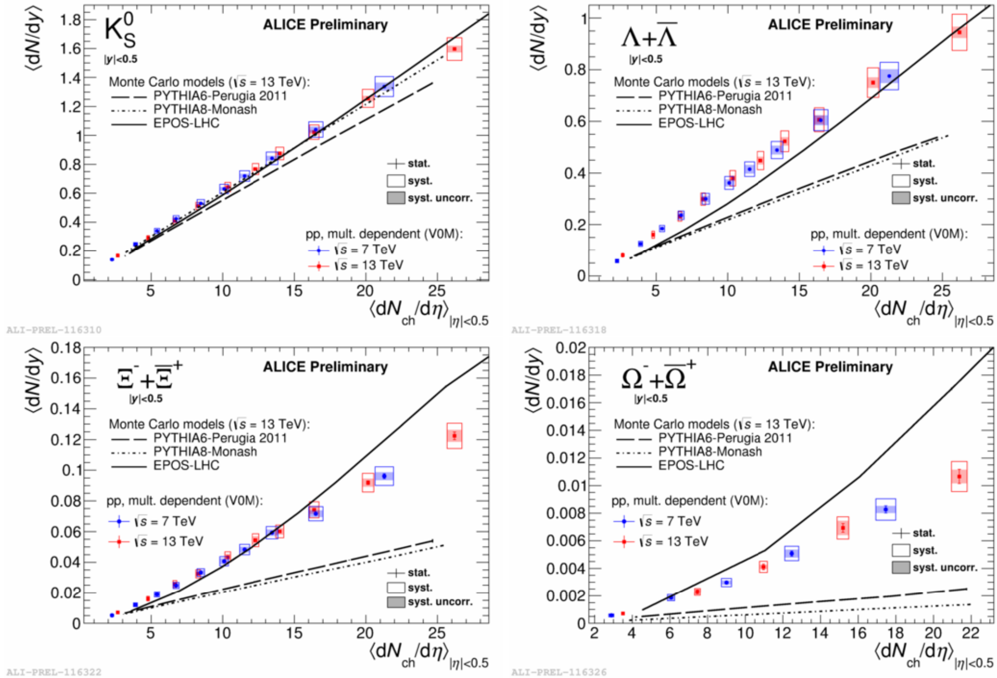

Fig. 2. p_T-integrated K^0_S, $\Lambda + \overline{\Lambda}$, $\Xi^- + \overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$ yields as a function of charged particle multiplicity at $|\eta| < 0.5$ measured in pp collisions at $\sqrt{s} = 7$ (red) and 13 (blue) TeV with comparison to EPOS-LHC [14] and PYTHIA6/PYTHIA8 [6] predictions.

comparison of p_T-integrated K^0_s, $\Lambda + \overline{\Lambda}$, $\Xi^- + \overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$ yields in pp collisions at $\sqrt{s} = 7$ and 13 TeV as a function of $\langle dN_{ch}/d\eta \rangle$ is shown in Fig. 2. We observe similar particle abundances at similar final state multiplicities for the two different center-of-mass energies, indicating that particle production is dominantly driven by the event activity and not by $\sqrt{s}$. The increase of yields with $\langle dN_{ch}/d\eta \rangle$ is stronger for hadrons with larger strangeness content, and given the saturation of p/π [3, 7], it indicates that this effect is related to strangeness enhancement (suppression) in large (small) systems and not to the baryonic number. A comparison to Monte Carlo predictions shows that the existing generators do not capture the evolution of (multi-) strange hadron yields with $\langle dN_{ch}/d\eta \rangle$: while both PYTHIA6/PYTHIA8 [6] and EPOS-LHC [14] describe K^0_s yields well, discrepancies between model predictions and data grow for baryons with larger strangeness content.

The mean transverse momentum $\langle p_T \rangle$ of K^0_s and $\Omega^- + \overline{\Omega}^+$ as a function of multiplicity measured in pp collisions at $\sqrt{s} = 7$ and 13 TeV is shown in Fig. 3. The MC models predict a hardening of the spectra with multiplicity, which is observed in data. However, the rate of hardening is not predicted correctly. We also observe a small increase of K^0_s $\langle p_T \rangle$ at higher $\sqrt{s}$ for similar final state multiplicities. Whether the same trend is observed in case of (multi-) strange baryons is not clear due to the present systematic uncertainties, but similar behavior has previously been reported at lower energies for charged particles [15].

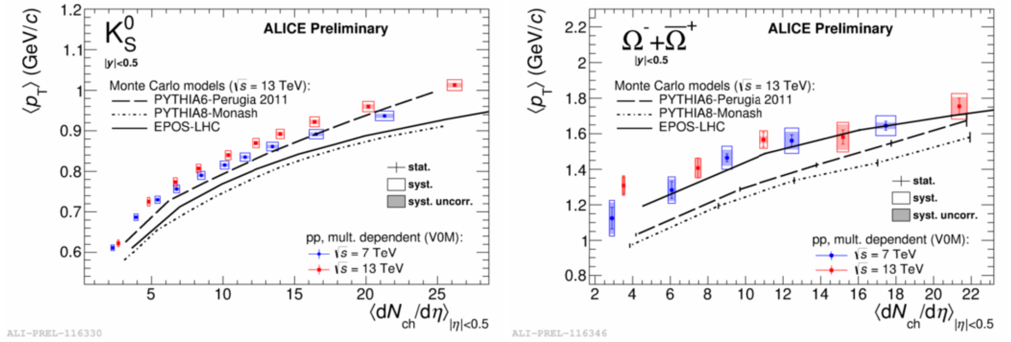

Fig. 3. $\langle p_T \rangle$ as a function of multiplicity for K^0_s (left) and $\Omega^- + \bar{\Omega}^+$ (right) measured in pp collisions at $\sqrt{s}$ = 7 (blue) and 13 TeV (red) with comparison to MC predictions.

3. Summary

The ALICE collaboration has measured and reported results on light flavor particle production as a function of multiplicity in pp collisions. To isolate the impact of $\sqrt{s}$ on final state observables, measurements in pp were performed for two different center-of-mass energies, 7 and 13 TeV. We observe a small blueshift of the maximum in p_T-differential p/π spectra ratio at $\sqrt{s}$ = 13 TeV as compared to lower energies, while no evolution is seen in K/π. The p_T-integrated p/π ratios saturate at LHC energies, while hyperon-over-pion ratios hint towards a small increase between $\sqrt{s}$ =7 and 13 TeV. The integrated hadron yields show a very good scaling behavior with event activity and are very similar at comparable $\langle dN_{ch}/d\eta \rangle$ for different collision energies. On the other hand, $\langle p_T \rangle$ of K^0_s exhibits an increase in $\sqrt{s}$ = 13 TeV pp collisions as compared to 7 TeV. This indicates that the hadrochemistry is dominantly driven by $\langle dN_{ch}/d\eta \rangle$, even though the dynamics of particle production might be different at different energies. Finally, the most common tunes of MC generators do not provide a satisfactory description of the evolution of these observables with multiplicity.

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